

# Project-domain Science Traceability and Alignment Framework (P-STAF): Analysis of a Payload Architecture

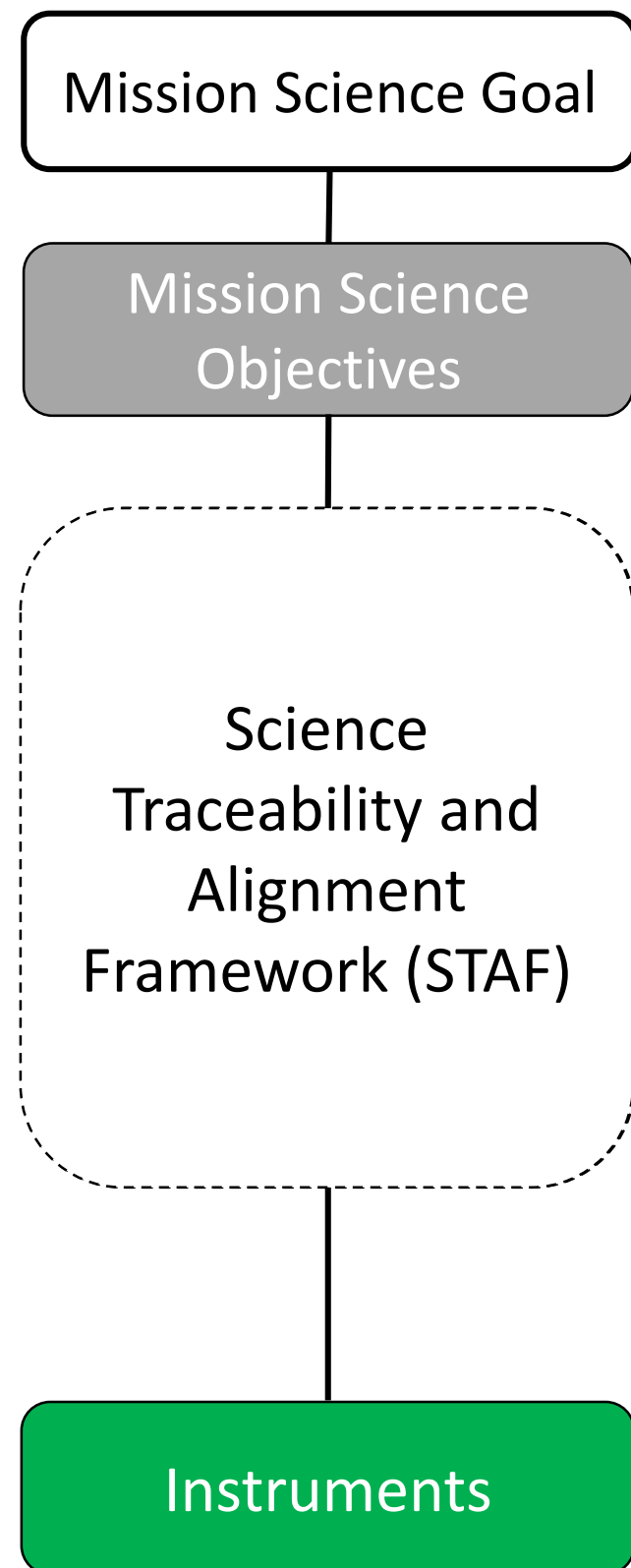
Laura Jones-Wilson, Sara Susca, Kirk Reinholtz

Jet Propulsion Laboratory, California Institute of Technology

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# Tracing Science Goals to Instruments



Negotiated with NASA HQ

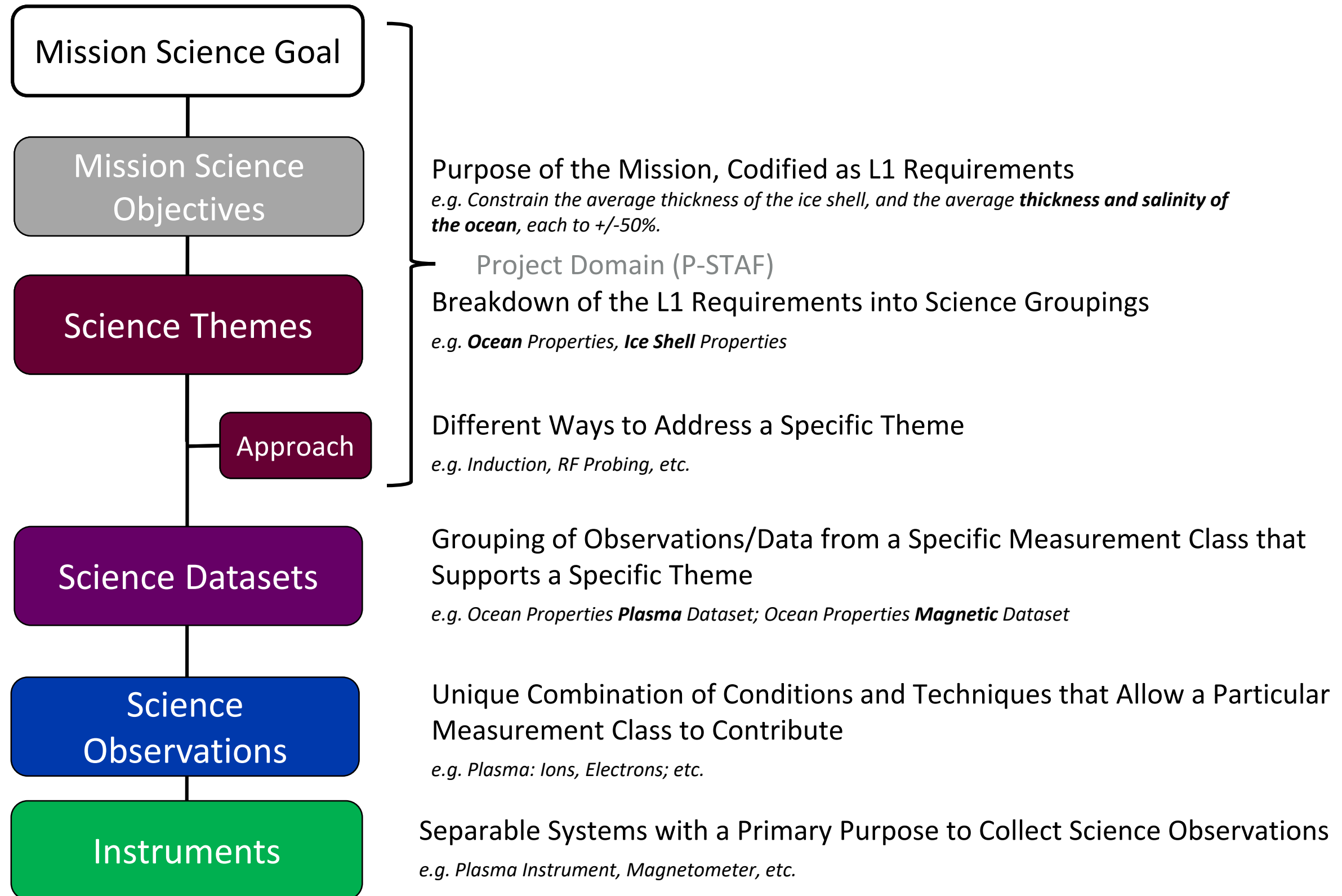
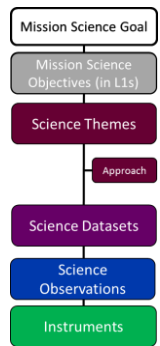
Described in our papers from last year's IEEE conference:

*Jones-Wilson, Laura; and Susca, Sara "A Framework for Extending the Science Traceability Matrix: Application to the Planned Europa Mission,"*

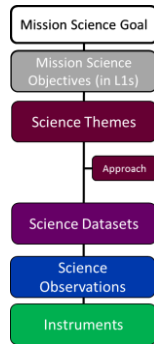
*Susca, Sara; Jones-Wilson, Laura; and Oida, Bogdan, "A Framework for Writing Measurement Requirements and its Application to the Planned Europa Mission"*

Selected by NASA HQ

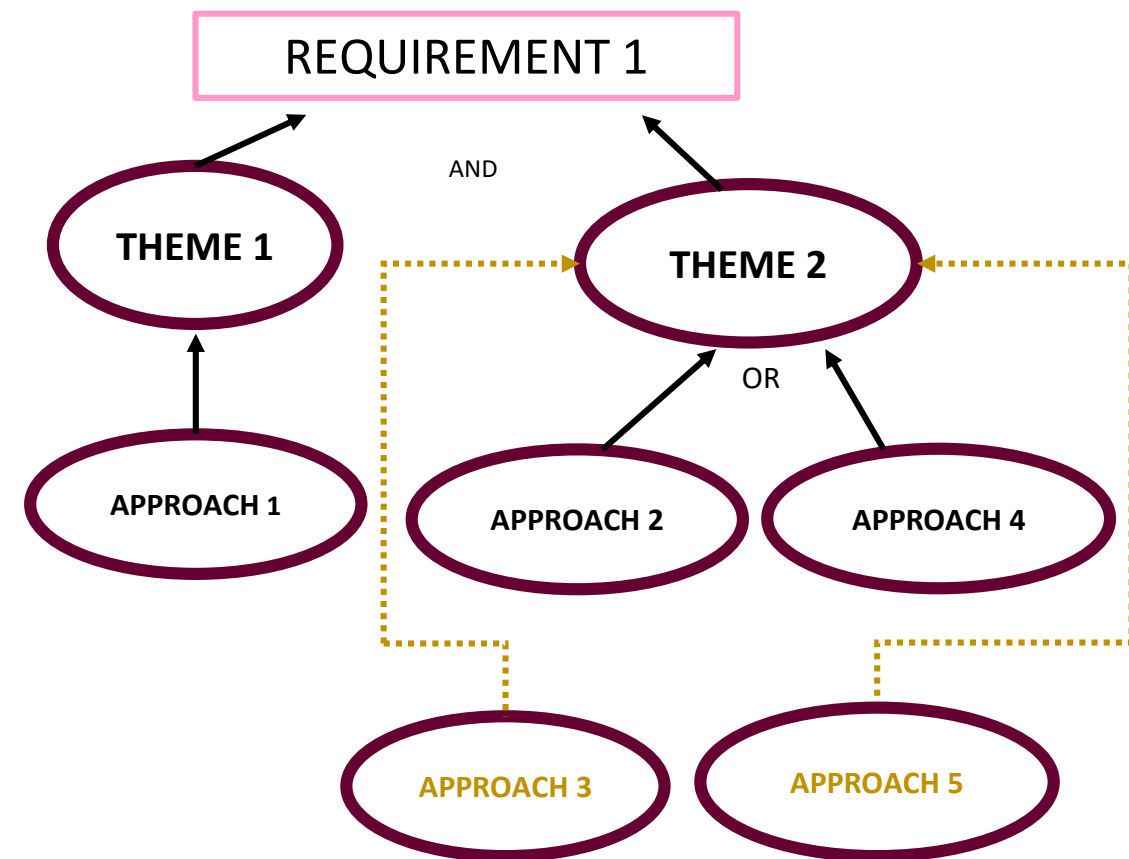
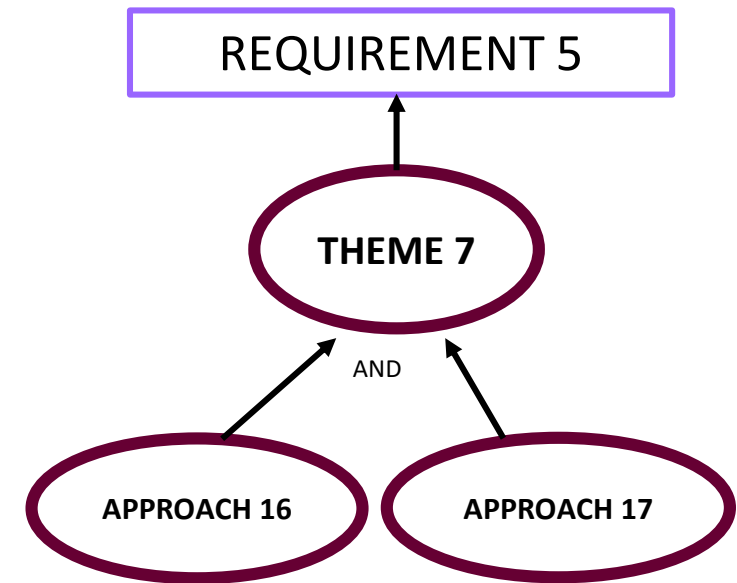
# Science Traceability and Alignment Framework



# Building a P-STAF Matrix

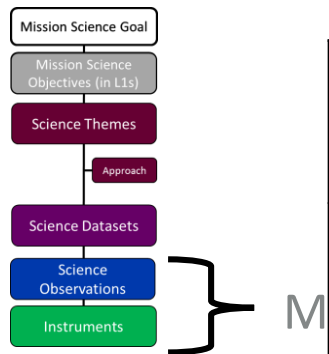


Mission Science Goal		Science Themes	Approach
MISSION OBJECTIVES	REQ1	Theme 1	Approach 1
	REQ2	Theme 2	Approach 2
			Approach 3
			Approach 4
			Approach 5
	REQ3	Theme 3	Approach 6
	REQ4	Theme 4	Approach 7
			Approach 8
			Approach 9
			Approach 10
			Approach 11
	REQ5	Theme 5	Approach 12
			Approach 13
			Approach 14
			Approach 15
	REQ6	Theme 6	Approach 16
		Theme 7	Approach 17
			Approach 18
		Theme 8	Approach 19
			Approach 20
			Approach 21
		Theme 9	Approach 22
			Approach 23
			Approach 24
		Theme 10	Approach 25
		Theme 11	Approach 25





# Building a P-STAF Matrix



Goal	L1 RQ Number	Science Themes	Coding of Theme to L1	Approach	Coding of Approach to Theme	Approach	
MISSION GOAL	REQ1	Theme 1	1	Approach 1	1	Approach 1	1
		Theme 2	1	Approach 2	1	Approach 2	1
				Approach 3	0	Approach 3	0
				Approach 4	2	Approach 4	2
				Approach 5	0	Approach 5	0
	REQ2	Theme 3	1	Approach 6	1	Approach 6	1
	REQ3	Theme 4	1	Approach 7	1	Approach 7	1
				Approach 8	2	Approach 8	2
	REQ4	Theme 5	1	Approach 9	1,2	Approach 9	1,2
				Approach 10	2	Approach 10	2
				Approach 11	1	Approach 11	1
		Theme 6	2	Approach 12	1,2	Approach 12	1,2
				Approach 13	1,2	Approach 13	1,2
				Approach 14	1	Approach 14	1
	REQ5	Theme 7	1	Approach 15	2	Approach 15	2
				Approach 16	1	Approach 16	1
	REQ6	Theme 8	1	Approach 17	1	Approach 17	1
				Approach 18	1	Approach 18	1
		Theme 9	2	Approach 19	2	Approach 19	2
				Approach 20	1,2	Approach 20	1,2
				Approach 21	1,2	Approach 21	1,2
				Approach 22	1	Approach 22	1
		Theme 10	1,2	Approach 23	2	Approach 23	2
				Approach 24	1	Approach 24	1
		Theme 11	0	Approach 25	1	Approach 25	1

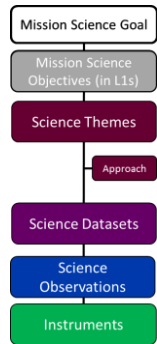
How do we map this to the Science Observations and Instruments?

Identified ways to contribute:

P	<b>Primary.</b> The instrument that can provide, most robustly and with greatest probability, the science data necessary to fully achieve a given approach as pertinent to a Theme, in the nominal mission plan. In indicated instances, data from a Supportive instrument also may be required.
I	<b>Independent.</b> An instrument (other than a Primary instrument) whose science data can enable a given approach as pertinent to a Theme to be achieved, though potentially less robustly than from a Primary instrument's data. Moreover, a change to the mission plan may be required for the data from an Independent instrument to achieve the approach in question.
S	<b>Supportive.</b> Said of an instrument whose science data is required to enable data from the Primary instrument to fully achieve a given approach as pertinent to a Theme.
E	<b>Enhancing.</b> Said of an instrument whose data is expected to further enhance the overall science return beyond that of data from a Primary or Independent instrument in achieving a given approach as pertinent to a Theme. There is no dependency implied between a Primary or Independent instrument and an Enhancing instrument.

P	Primary
I	Independent
S	Supporting
E	Enhancing

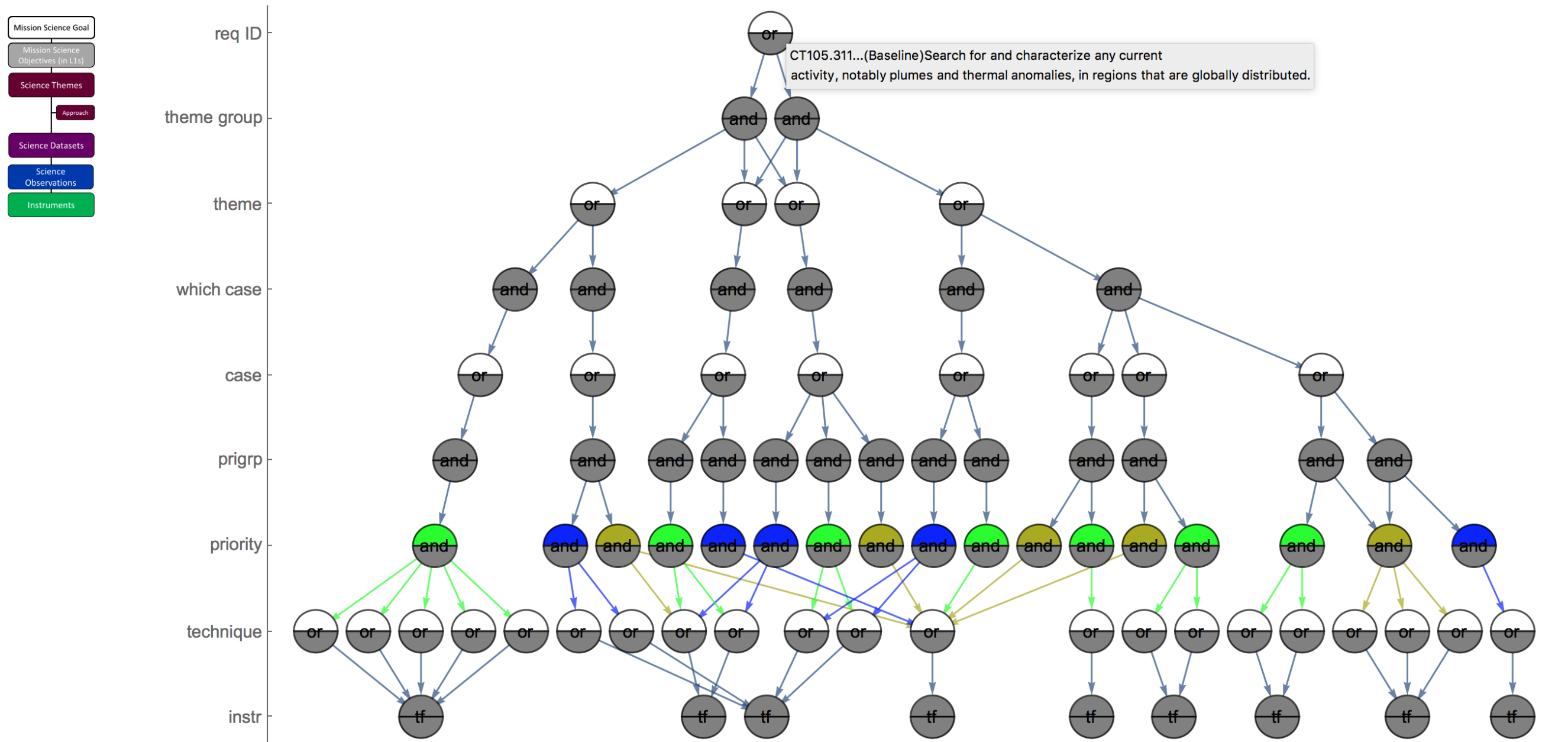
# Full P-STAF Matrix



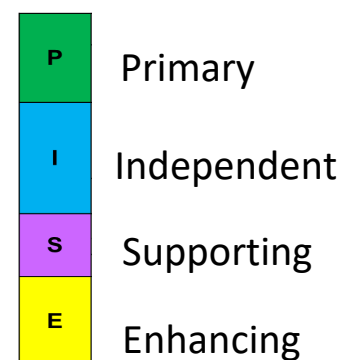
Goal	L1 RQ Number	Science Themes	Coding of Theme to L1	Approach	Coding of Approach to Theme	Inst A		Inst B		Inst C				Inst D		Inst E			Inst F		Inst G		Inst H		Inst I	
						Obs A	Obs B	Obs C	Obs D	Obs E	Obs F	Obs G	Obs H	Obs I	Obs J	Obs K	Obs L	Obs M	Obs N	Obs O	Obs P	Obs R				
MISSION GOAL	REQ1	Theme 1	1	Approach 1	1		P1	P1					S1													
		Theme 2	1	Approach 2	1	E												P1								
				Approach 3	0		P1	P2					E						E							
				Approach 4	2																				P1	
				Approach 5	0					I2															E	
	REQ2	Theme 3	1	Approach 6	1							E		P1	E	E				E						
	REQ3	Theme 4	1	Approach 7	1							E		P1						E						
				Approach 8	2							E		P1	I2	I2				E						
	REQ4	Theme 5	1	Approach 9	1,2	P1			E									I2								
				Approach 10	2									P1												
				Approach 11	1									E	I2	I3	I4	P1								
				Approach 12	1,2									E						P1	E					
		Theme 6	2	Approach 13	1,2	P1												I2								
				Approach 14	1									E		P1										
				Approach 15	2									E										P1		
	REQ5	Theme 7	1	Approach 16	1					P1									E							
				Approach 17	1			I2											P1	P1						
	REQ6	Theme 8	1	Approach 18	1										P2	P1	I3									
				Approach 19	2					P1																
		Theme 9	2	Approach 20	1,2															P1	E					
				Approach 21	1,2									I1												
				Approach 22	1	S1												I1								
				Approach 23	2	P1			E									I2								
		Theme 10	1,2	Approach 24	1		E	E			E			I2					P1							
		Theme 11	0	Approach 25	1						P2	P1		I3	I4	I5			I6	E						

P	Primary
I	Independent
S	Supporting
E	Enhancing

# A Queryable Network



- Robustness of the L1s/themes/approaches
- Criticality of a given instrument/observation to the L1s/themes/approaches and visa versa
- Scope of a given L1/theme/approach



# P-STAF Graph Analysis Tools

### Roll Up to the Theme vs Instruments

Goal	L1 RQ Number	Science Themes	Coding of Theme to L1	Inst A	Inst B	Inst C	Inst D	Inst E	Inst F	Inst G	Inst H	Inst I
MISSION GOAL	REQ1	Theme 1	1		P	S						
		Theme 2	1	E	E	E			P	E		P
	REQ2	Theme 3	1			E	P	E			E	
	REQ3	Theme 4	1			E	P	I			E	
	REQ4	Theme 5	1	P	E		P	I	P		P	
		Theme 6	2	P			E	P	I		P	
	REQ5	Theme 7	1		I	P				P	P	
	REQ6	Theme 8	1			P		P				
		Theme 9	2	P	E		I		I		P	
		Theme 10	1,2		E	E	I			P		
		Theme 11	0			P	I	I		I	E	

### Back-up/Enhancing Scope

Observations that are <b>at most</b> Independent
Obs E
Obs L
Observations that are <b>only</b> Enhancing
Obs D
Obs H

### Determine “Minimal Sets”

Mission	N of Combos	N of Inst in Combo	Inst A	Inst B	Inst C	Inst D	Inst E	Inst F	Inst G	Inst H	Inst I	Inst J	Inst K	Inst L	Inst M	Inst N
Baseline L1s	2	9	1	1	1	1	1	0	1	1	1	1	0	0		
		9	1	1	1	1	1	0	0	1	1	1	1	1	0	
Threshold L1s	18	4	0	1	1	0	0	0	1	0	0	0	0	0	1	
		4	0	1	0	1	0	0	1	0	0	0	0	0	0	1
		4	1	0	1	0	0	0	1	1	0	0	0	0	0	0
		4	1	0	0	1	0	0	1	1	0	0	0	0	0	0
		4	0	1	1	0	0	0	1	1	0	0	0	0	0	0
		4	0	1	0	1	0	0	1	1	0	0	0	0	0	0
		5	0	1	1	0	1	0	0	0	0	0	0	1	1	1
		5	0	1	0	1	1	0	0	0	0	0	0	1	1	1
		5	0	1	1	0	1	0	0	0	0	1	0	1	0	1
		5	1	0	1	0	1	0	0	0	0	1	0	0	1	0
		5	1	0	0	1	1	0	0	1	0	0	1	0	0	0
		5	1	0	1	0	1	0	0	1	0	1	0	0	0	0
		5	1	0	0	1	1	0	0	1	0	1	0	0	0	0
		5	0	1	1	0	1	0	0	1	0	0	1	0	0	0
		5	0	1	0	1	1	0	0	1	0	0	1	0	0	0
		5	0	1	1	0	1	0	0	1	0	1	0	0	0	0
		5	0	1	0	1	1	0	0	1	0	1	0	0	0	0

All ways to achieve L1s:

Robustness and Scope

# Scope, Risk, and Robustness of L1 Req. Criticality

[Truth Tables]

All ways to fail L1s:

Criticality

[Cut Set Tables]

# Paths an Instrument Influences

REQ to Inst Truth Table	# Inst	Inst A	Inst B	Inst C	Inst D	Inst E	Inst F	Inst G	Inst H	Inst I	Inst J	Inst K	Inst L	Inst M	Inst N
REQ1	3	0	1	1											
REQ1	3	0	1	1											
REQ2	1	0	0	0											
REQ3	1														
REQ3	1														
REQ4	2														
REQ4	2														
REQ4	2														
REQ4	2														
REQ5	2														
REQ5	3														
REQ6	3														
REQ6	2														
REQ6	2														
REQ6	2														
REQ6	3														
REQ6	2														
REQ7	2														
REQ8	3														
REQ9	10														

Robustness	Scope	Criticality
# of Unique Combos of Instruments to Satisfy	Min # of Instruments to Satisfy	# of Instrument Single-Point Failures
1	4	4
1	6	6
1	1	1
2	1	0
4	3	1
1	2	2
2	1	0
3	1	0
10	2	0

Breadth (P/I/S)	All (+Enhancing) Breadth	Criticality
Total #	202 Branches	25 Nodes
148 Branches	215 Branches	11 Nodes
152 Branches	218 Branches	6 Nodes
124 Branches		
% of the Non-Enhancing Branches to Approach Influenced by the Instrument	% of All Branches to Approach Influenced by the Instrument	% of Approaches that Fail if Instrument Fails Alone
% of the Non-Enhancing Branches to Theme Influenced by the Instrument	% of All Branches to Theme Influenced by the Instrument	Number of Themes that Fail if Instrument Fails Alone
% of the Non-Enhancing Branches to L1s Influenced by the Instrument	% of All Branches to L1s Influenced by the Instrument	Number of L1s that Fail if Instrument Fails Alone
Inst A	7%	4%
Inst B	10%	8%
Inst C	18%	16%
Inst D	17%	16%
Inst E	11%	8%
Inst F	5%	8%
Inst G	20%	0%
Inst H	7%	12%
Inst I	7%	4%



# Conclusions

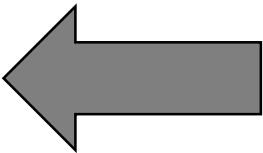
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- The P-STAF Matrix is a powerful way to show science traceability and dependencies among different approaches and themes
- When properly formulated, a network analysis of the matrix can be used to evaluate the robustness, criticality, and scope of a payload architecture against a set of L1 requirements
- These results can highlight risks and strengths of a given architecture
- This kind of information can be used to inform trade studies and risk management policies on the project
- Remember that the tools can only analyze the data in the graph – and the graph can only capture relationships we know and understand... and discoveries often happen in the space where we did not expect to see a relationship

EXTRA material

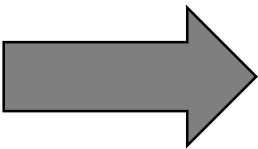
# Mission Analysis: Roll Up and Minimal Sets

				Inst A	Inst B	Inst C	Inst D	Inst E	Inst F	Inst G	Inst H	Inst I
Goal	L1 RQ Number	Science Themes	Coding of Theme to L1									
MISSION GOAL	REQ1	Theme 1	1		P	S						
		Theme 2	1	E	E	E			P	E		P
	REQ2	Theme 3	1			E	P	E			E	
	REQ3	Theme 4	1			E	P	I			E	
	REQ4	Theme 5	1	P	E		P	I	P		P	
		Theme 6	2	P			E	P	I		P	
	REQ5	Theme 7	1		I	P				P		
	REQ6	Theme 8	1			P		P				
		Theme 9	2	P	E		I		I		P	
		Theme 10	1,2		E	E	I			P		
		Theme 11	0			P	I	I		I	E	



Roll Up to the Theme vs Instruments for a birds-eye view of the mission.

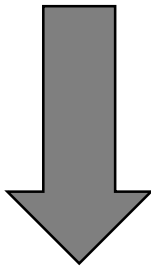
How many instruments are “minimally” needed to achieve the mission?



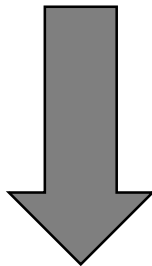
Mission	N of Combs	N of Inst in Combo	Inst A	Inst B	Inst C	Inst D	Inst E	Inst F	Inst G	Inst H	Inst I	Inst J	Inst K	Inst L
Baseline L1s	2	9	1	1	1	1	1	0	1	1	1	1	0	0
		9	1	1	1	1	1	0	0	1	1	1	1	0
Threshold L1s	18	4	0	1	1	0	0	0	1	0	0	0	0	1
		4	0	1	0	1	0	0	1	0	0	0	0	1
		4	1	0	1	0	0	0	1	1	0	0	0	0
		4	1	0	0	1	0	0	1	1	0	0	0	0
		4	0	1	1	0	0	0	1	1	0	0	0	0
		4	0	1	0	1	0	0	1	1	0	0	0	0
		5	0	1	1	0	1	0	0	0	0	0	1	1
		5	0	1	0	1	1	0	0	0	0	0	1	1
		5	0	1	1	0	1	0	0	0	0	1	0	1
		5	0	1	0	1	1	0	0	0	0	1	0	1
		5	1	0	1	0	1	0	0	1	0	0	1	0
		5	1	0	0	1	1	0	0	1	0	0	1	0
		5	1	0	1	0	1	0	0	1	0	1	0	0
		5	1	0	0	1	1	0	0	1	0	1	0	0
		5	0	1	1	0	1	0	0	1	0	0	1	0
		5	0	1	0	1	1	0	0	1	0	0	1	0
		5	0	1	1	0	1	0	0	1	0	1	0	0
		5	0	1	0	1	1	0	0	1	0	1	0	0

# L1s Analysis: Robustness, Scope, and SPF

All the way to achieve any L1: **Robustness**  
and **Scope** [Truth Tables]



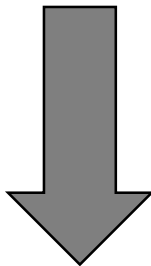
All the way to fail any L1: **Criticality** [Cut set Tables]



REQ to Inst Truth Table	# Inst	Inst A	Inst B	Robustness		Scope		Criticality		Inst G	Inst H	Inst I
				# of Unique Combos of Instruments to Satisfy	# of Unique Combos of Observation Types to Satisfy	Min # of Instruments to Satisfy	Min # of Observation Types to Satisfy	# of Instrument Single-Point Failures	# of Observation Type Single-Point Failures			
REQ1	3	0	1								0	0
REQ1	3	0	1								0	0
REQ2	1	0	0								0	1
RQ1	RQ1			1	2	4	7	4	5		0	0
RQ2	RQ2			1	1	6	8	6	8		0	0
RQ3	RQ3			1	1	1	1	1	1		0	0
RQ4	RQ4			2	2	1	1	0	0		1	0
RQ5	RQ5			4	20	3	6	1	3		0	0
RQ6	RQ6			1	1	2	2	2	2		1	0
RQ7	RQ7			2	2	1	1	0	0		0	0
RQ8	RQ8			3	4	1	1	0	0		1	0
RQ9	RQ9			10	28	2	2	0	0		0	0

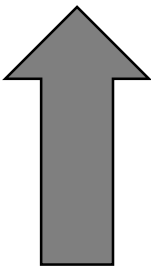
# Inst/Obs Analysis: Breadth, Back-Up Scope, and Enhancing

How many paths does each instrument influence?



Instruments that are <b>at most</b> Independent
Inst F
Inst ...

Instruments that are <b>only</b> Enhancing
Inst G
Inst ...

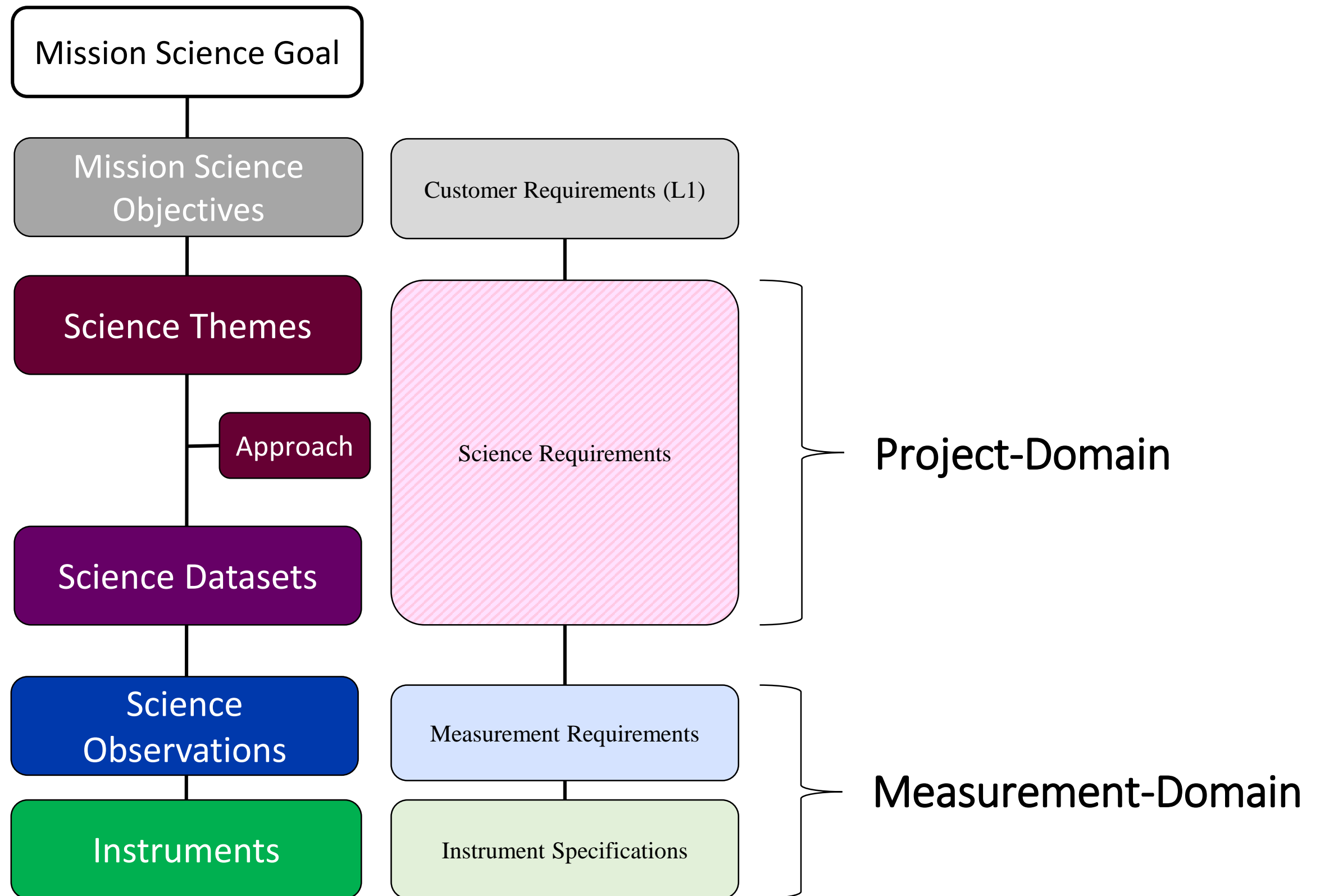


Which Inst/Obs is **back-up** scope? Which is **only enhancing**?

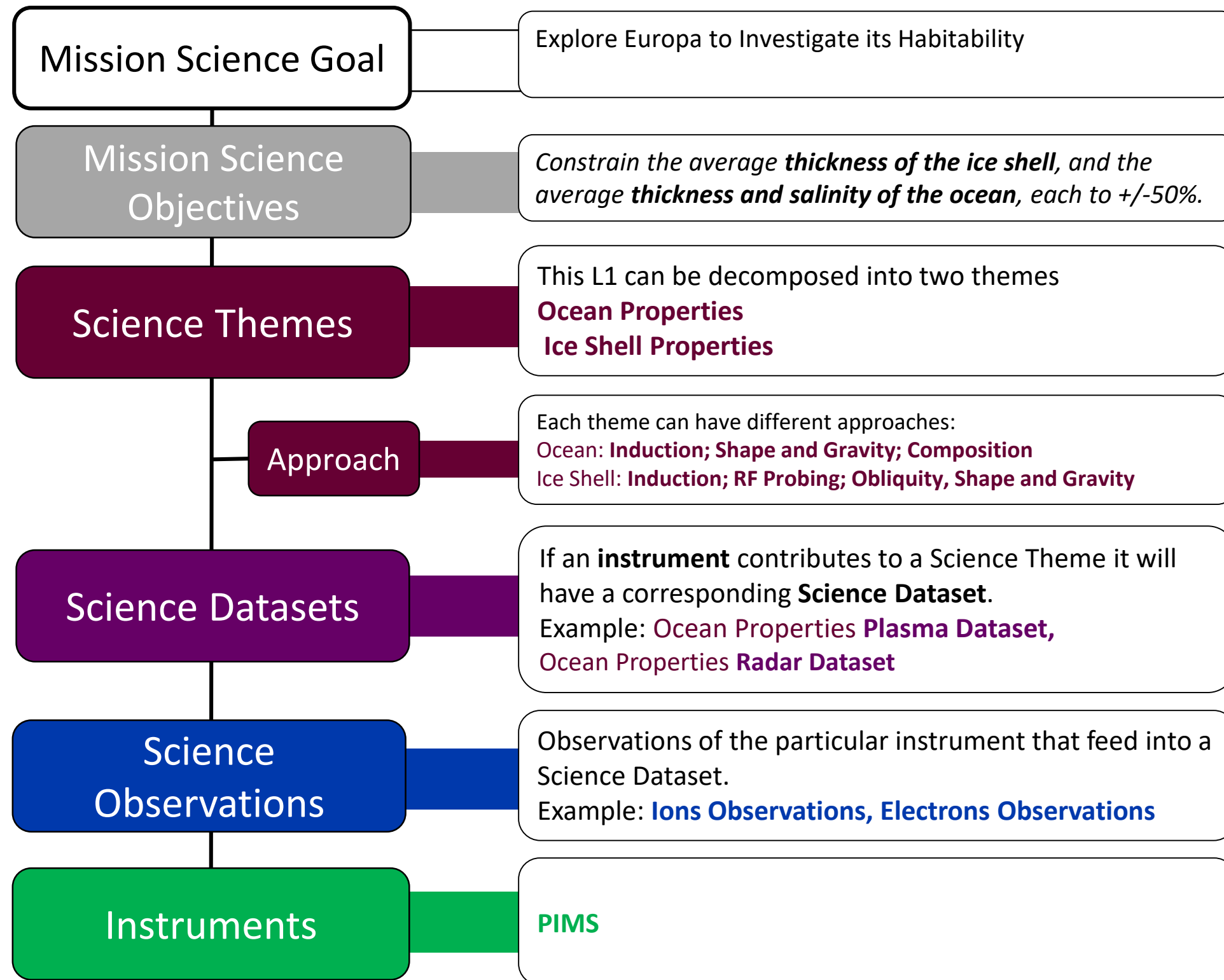
	Breadth (P/I/S)			All (+Enhancing) Breadth			Criticality		
Total Number	148 Branches	152 Branches	124 Branches	202 Branches	215 Branches	218 Branches	65 Nodes	29 Nodes	17 Nodes (9BL)
Instrument	% of the Non-Enhancing Branches to Approach Influenced by the Instrument	% of the Non-Enhancing Branches to Theme Influenced by the Instrument	% of the Non-Enhancing Branches to L1s Influenced by the Instrument	% of All Branches to Approach Influenced by the Instrument	% of All Branches to Theme Influenced by the Instrument	% of All Branches to L1s Influenced by the Instrument	% of Approaches that Fail if Instrument Fails Alone	Number of Themes that Fail if Instrument Fails Alone	Number of L1s that Fail if Instrument Fails Alone
Inst A	7%	6%	6%	11%	11%	11%	5%	10%	12%
Inst B	10%	9%	9%	14%	13%	14%	9%	10%	12%
Inst C	18%	16%	15%	25%	24%	24%	9%	14%	18%
Inst D	17%	16%	16%	26%	25%	25%	11%	14%	18%
Inst E	11%	11%	9%	17%	17%	17%	6%	3%	6%
Inst F	5%	5%	3%	10%	9%	10%	0%	0%	0%
Inst G	20%	19%	17%	21%	20%	19%	3%	0%	0%
Inst H	7%	8%	10%	5%	6%	6%	9%	7%	6%
Inst I	7%	8%	10%	6%	7%	6%	6%	7%	6%



# Science Traceability and Alignment Framework



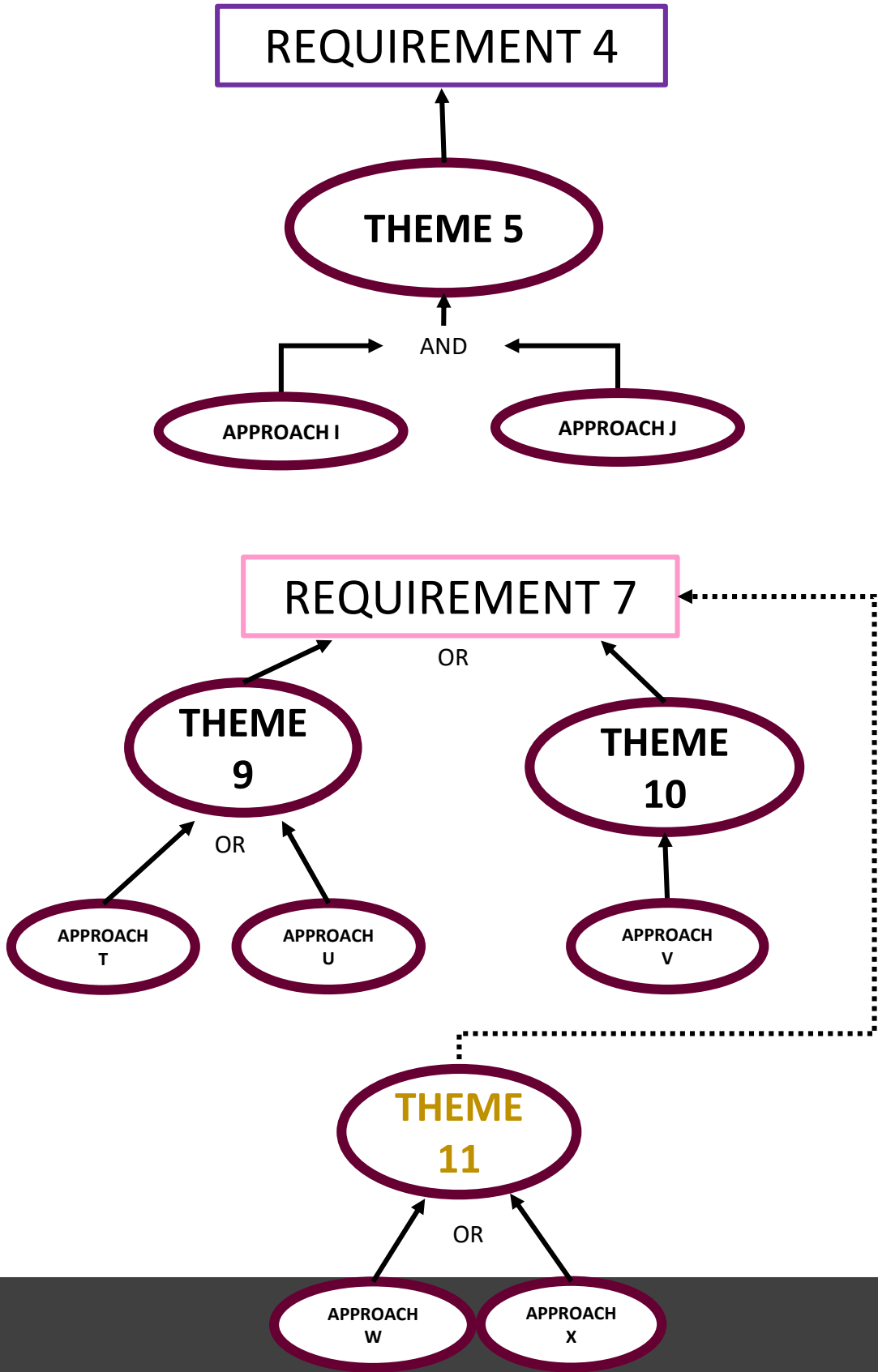
# STAF Taxonomy Example



# Example P-STAF Logic: Examples



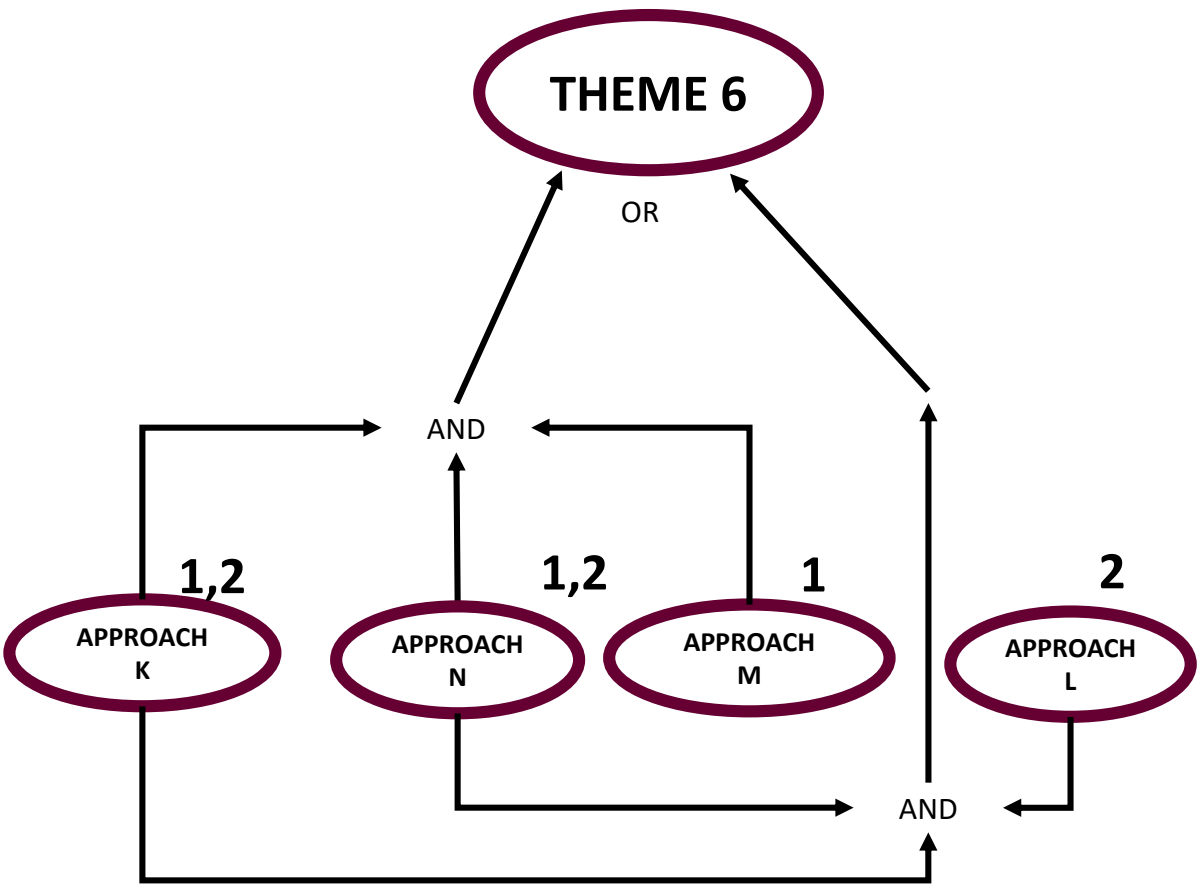
Goal	Cat.	BLID	Science Themes		Approaches	
MISSION GOAL	CAT 1	RQ1	THEME 1	1	APPROACH A	1
		RQ2	THEME 2	1	APPROACH B	1
			THEME 3	2	APPROACH C	1
					APPROACH D	1
					APPROACH E	0
					APPROACH F	2
	CAT 2	RQ3	THEME 4	1	APPROACH G	0
		RQ4	THEME 5	1	APPROACH H	1
					APPROACH I	1
					APPROACH J	1
		RQ5	THEME 6	1	APPROACH K	1,2
					APPROACH L	2
					APPROACH M	1
					APPROACH N	1,2
			THEME 7	1	APPROACH O	1
					APPROACH P	1
APPROACH Q	0					
APPROACH R	2					
CAT 3	RQ6	THEME 8	1	APPROACH S	1	
CAT 4	RQ7	THEME 9	1	APPROACH T	1	
		THEME 9	1	APPROACH U	2	
		THEME 10	2	APPROACH V	1	
		THEME 11	0	APPROACH W	1	
				APPROACH X	2	



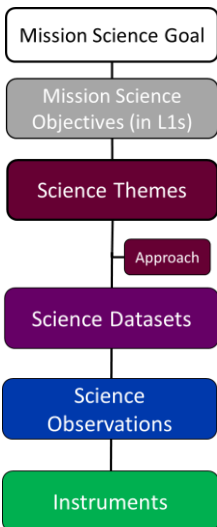
# Example P-STAF Logic: Examples



Goal	Cat.	BLID	Science Themes		Approaches	
MISSION GOAL	CAT 1	RQ1	THEME 1	1	APPROACH A	1
			THEME 2	1	APPROACH B	1
		RQ2	THEME 3	2	APPROACH C	1
					APPROACH D	1
					APPROACH E	0
					APPROACH F	2
	CAT 2	RQ3	THEME 4	1	APPROACH G	0
					APPROACH H	1
		RQ4	THEME 5	1	APPROACH I	1
					APPROACH J	1
		RQ5	THEME 6	1	APPROACH K	1,2
					APPROACH L	2
					APPROACH M	1
					APPROACH N	1,2
			THEME 7	1	APPROACH O	1
					APPROACH P	1
					APPROACH Q	0
					APPROACH R	2
	CAT 3	RQ6	THEME 8	1	APPROACH S	1
	CAT 4	RQ7	THEME 9	1	APPROACH T	1
					APPROACH U	2
			THEME 10	2	APPROACH V	1
			THEME 11	0	APPROACH W	1
					APPROACH X	2



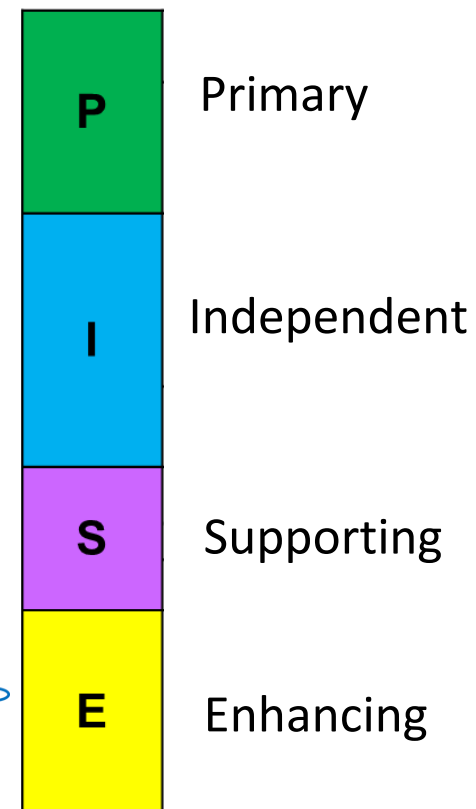
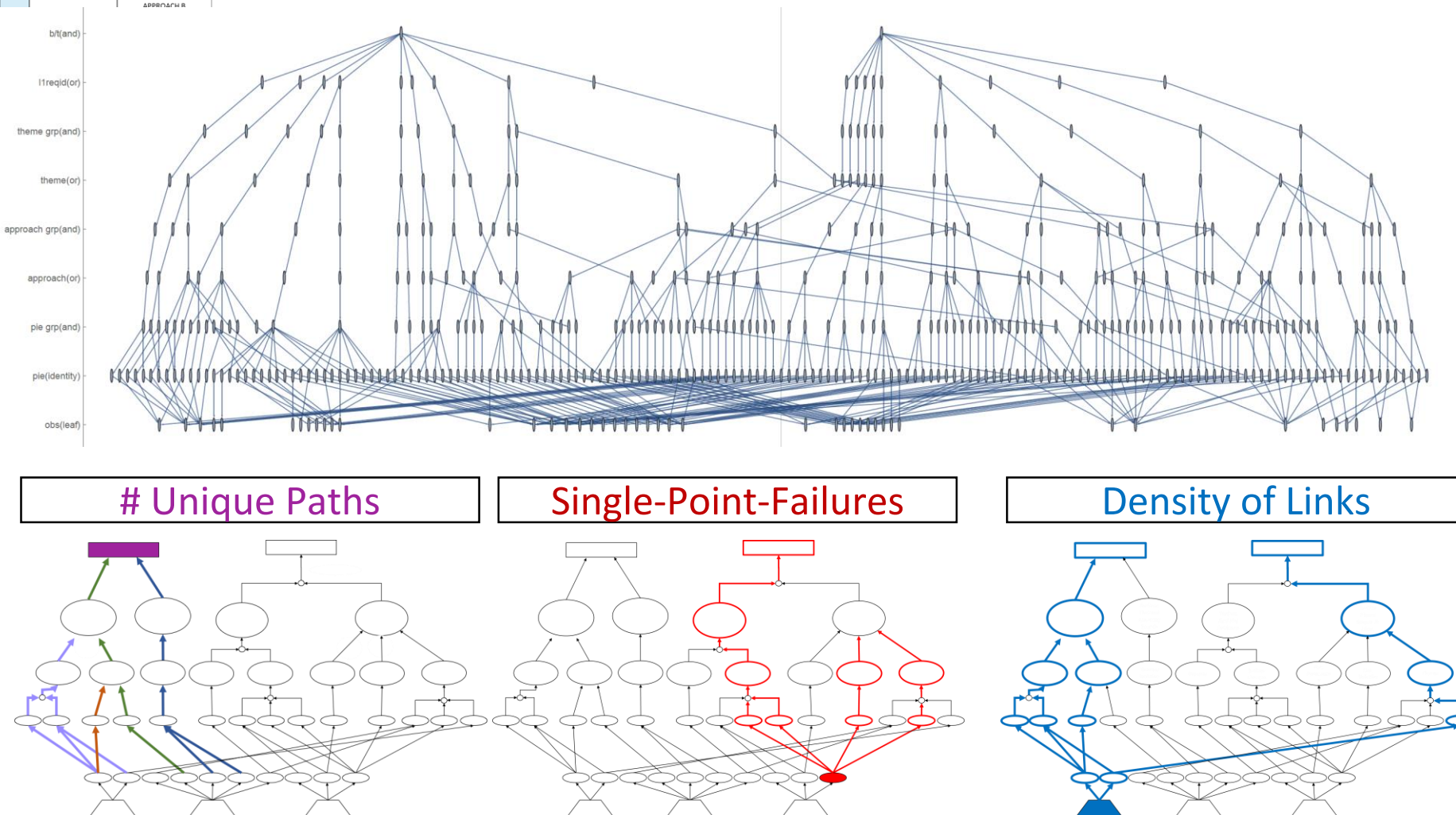
# Raw P-STAF Matrix



L1, Science Theme, Approach

Goal	Cat.	BLID	Science Themes	Approaches
	RQ1	THEME 1		APPROACH A
				APPROACH B

Science Observations by Measurement Class



Questions about the Payload Architecture:

- In how many independent ways can each L1 be met?
- Which L1s have single point of failures?
- If an instrument/observation fails, which L1s are not achievable?
- How many paths does an instrument affects?



# Blue-Green Index

- For a selected combination of instruments
  - The **Mission** Blue-Green index is the average of the L1s Blue-Green Indices.
  - The **L1** Blue-Green Index is the *average (\*)* of the its Themes Blue-Green Indices
  - The **Theme** Blue-Green Index is the *average (\*)* of its Approaches Blue-Green Indices
  - The **Approach** Blue-Green Index is
    - **Blue** (i.e. 0) if the instrument that is **Independent** for that approach appears in the selected combination of instruments
    - **Green** (i.e. 1) if the instrument that is **Primary** for that approach appears in the selected combination of instruments

For the minimal set of 10 instruments that achieves the Baseline Mission Success

B/T	L1 RQ Number	L1 Blue-Green Index
BASELINE	RQ106.312	Green
	RQ106.317	Green
	RQ106.318	Green
	RQ106.313	Green
	RQ106.316	Green
	RQ106.320	Green
	RQ106.319	Green
	RQ106.311	Green
	RQ106.314	33% Blue-66% Green
	Mission Blue-Green Index	93%

For any of the minimal sets with 4 instruments that achieve the Threshold Mission Success

B/T	L1 RQ Number	L1 Blue-Green Index
THRESHOLD	RQ106.323	Green
	RQ106.325	Green
	RQ106.328	Blue
	RQ106.327	Blue
	RQ106.321	50% Blue-50% Green
	RQ106.322	Green
	RQ106.326	Green
	N/A	
	RQ106.324	Green
	Mission Blue-Green Index	69%

- (\*) A **Theme/L1** is either a AND node or a OR node.
  - For a AND theme/L1 node:
    - The theme/L1 Blue-Green Index is the average of its approaches/themes Blue-Green Indices
  - For OR theme/L1 node:
    - if at least one of the approaches/theme is green, the theme Blue-Green Index is green (i.e., 1) else it is blue (i.e., 0)